[254] 5/-

VS RESTRICTED CIRCULATION

This paper is not an official document; it is for information only and must not be quoted in any printed publication.

Agricultural Memorandum No 972

The estimation of average daily radiation amounts from cloud observations - an example for Austria.

by C J Hume and L D J Harvey

1. Introduction

This note describes a method devised to estimate weekly (or monthly) averages of daily solar radiation totals using average cloud cover.

The need for a method arose during the joint Meteorological Office/GRI study of the effects of climatic change on herbage production in Europe. (EEC Contract CLI-05-81-UK(H)). Weekly averages of daily solar radiation totals at a number of sites in Austria were required in order to model the growth of grass. The Austrian Meteorological Service was unable to supply sunshine or radiation data in a machineable form for the sites concerned and attention was given to devising a method by which radiation totals could be estimated using whatever data was available - in this case measurements (at 07, 14 and 21 hours only) of total cloud cover.

Although developed specifically for Austria the basic philosophy should be applicable elsewhere.

2. Method

2.1 Theory

The Austrian data set contains observations of total cloud cover (in tenths) made three times per day; the mean of these three values is taken to be the mean cloud cover during the day (N_s). Kondratyev (1973) quotes the Savinov-Angstrom formula for climatological computation of radiation totals:

$$R_s = R\,(1 - (1-K_s)N_s) \quad \ldots\ldots\ldots (1)$$

where R_s = the observed total radiation (summed over a period) falling on unit horizontal area

F42B

R = the value of R_s which would be measured in the absence of cloud

K_s = an empirical coefficient of transmission of solar radiation through cloud

On the basis of observations made in the Austrian Alps (Dirmhirn(1951) found K_s to depend upon the height of the site (h, metres):

$$K_s = 0.01\ (21 + 0.0075h) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

In this note, the period of summation for R, R_s will be taken as one day. The Angstrom equation can be used to estimate R:

$$R = R_a\ (a + bS/So) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

where R_a = the daily total solar radiation falling on unit area at the top of the atmosphere

S = the actual sunshine duration

S_o = the maximum possible sunshine duration

Inserting $S/S_o = 1$ to represent a cloud free atmosphere gives:

$$R = R_a\ (a+b) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (3a)$$

Dogniaux and Lemoine (1982) have correlated sunshine and radiation measurements made in many countries and find that a, b and (a+b) can be linearly related to the latitude (ϕ, degrees) of the individual sites; in particular:

$$(a+b) = A+B\phi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (4)$$

The coefficients a,b show, when calculated on a monthly basis, no systematic seasonal trend and here the values calculcated on an annual basis are used to yield

$$(a+b) = 0.68115 + 0.00201\ \phi \quad \ldots\ldots\ldots\ldots\ (4a)$$

The quantity(a+b) is an average atmospheric turbidity index (ATI). Individual sites at the same latitude will have differing values of the ATI depending upon local sources of turbidity. The ATI may be

re-written as

$$ATI = (a+b) + P$$

where P represents local effects.

Dogniaux and Lemoine (1982) suggest that for rural temperate sites (taken to be a reasonable description of the (generally non-industrial) Austrian locations) P is small (approx 0.02, sd 0.02).

Equation (1) can be written:

$$R_s = R_a\,(0.68115 + 0.00201\phi + P)(1 - (1-K_s)N_s) \quad \ldots\ldots\ (5)$$

A good estimate of R_a may be obtained by straightforward calculation (e.g. Thompson (1982)):

$$R_a = 3600S \quad \ldots\ldots\ (6)$$

where S = solar irradiance (w/m^2) on day number d (from Jan 1st) given by

$$S = 1360\,(1 + 0.0335\cos(\tfrac{2\pi d}{365})) \quad \ldots\ldots\ (6a)$$

The solar declination δ is given by:

$$\delta = 0.41\cos\left(2\pi\,\frac{(d-172)}{365}\right) \quad \ldots\ldots\ (6b)$$

The local time of sunrise, t_1 is given by:

$$t_1 = \frac{12}{\pi}\cos^{-1}\left[\tan\delta.\tan\phi + \frac{0.0145}{\cos\delta\cos\phi}\right] \quad \ldots\ldots\ (6c)$$

where sunrise is assumed to occur when the centre of the sun is 50' below the horizon (but made visible by refraction).

3. Results

3.1 Estimation of the best equation

Daily radiation totals for one of the Austrian sites (Graz) under consideration has been published in manuscript form (Zentralanstadt fur Meteorologie and Geodynamik, Publikation Nr 178, Parts 4-16) and has been used to examine the performance of eqn (5).

Noting the latitude and height of Graz are respectively 46.97 degree N and 340m, equation (5) becomes

$$R_s = R_a\ (0.7756\ +\ P)(1-0.7645N_s\ )\ .....\ (7)$$

In fig.1 the solid line shows the value of R_s/R_a as a function of N_s (setting P = 0).

For each month of the years 1964 to 1977 the monthly average of daily solar radiation total has been extracted from the published data. The monthly figures have been averaged over the 14 year period and expressed as a fraction of the month's mean daily total radiation received at the top of the atmosphere. The points in fig.1 show this fraction plotted as a function of the corresponding monthly means of the average daily cloud cover.

The dashed line of fig.1 is the best fit straight line through the points and is in fair agreement with the calculated (solid) line over the small range of cloud cover concerned (5/10 to 7/10). The calculated line can be shifted using the parameter P; inserting a value of -0.0079 forces the calculated line to pass through the centre of gravity of the data points (the dash-dot line). This value of P is consistent with that suggested in section 2.

The degree of agreement between the best-fit straight line and the calculated straight line (with P = -0.0079) is encouraging; however, extrapolation of the best fit line outside the observed range of cloud cover may not be justified; in view of the reasonable agreement between the data points and the calculated line the latter will be used to estimate daily radiation totals. Thus equation (7) becomes

$$R_s = Ra\ 0.7677\ \ (1-0.7645N_s)\ \ .....\ \ (7\ )$$

and, for Austrian sites generally, equation (5) becomes

$$R_s = Ra\ (0.67914 + 0.00201\phi)(1-(1-K_s)N_s)\ .....\ (8)$$

3.2 Assessment of the best equation

In order to assess the accuracy of equation (8) weekly means of daily solar radiation totals were extracted from the published data and compared with values calculated by the equation.

Figure 2 shows a plot of ϵ at various times during the years, where ϵ is the fractional r.m.s error defined by:

$$\epsilon = \left[\left(\frac{R_s(\text{observed}) - R_s(\text{calculated})}{R_s(\text{observed})} \right)^2 / N \right]^{1/2}$$

where N is the number of years of data available for each week (typically 10 up to a maximum of 14 years).

It can be seen that the error is a minimum in mid-summer (June/July) and increases markedly during autumn and early winter. During the summer months (of say April-Sept) it would thus appear that equation (7) may be used to calculate weekly means of daily solar radiation totals to within about $\pm$ 12%. (the average value of ϵ from April-Sept).

Monthly means of daily radiation totals as calculated by equation (7) have also been compared with observed totals. Figure 3 shows ϵ as a function of month. A typical figure for April to September is $\pm$ 7%.

A limited (because it has to be done by hand) amount of data has been extracted on a daily basis and the values of ϵ shown in fig 4; the average during April-September is $\pm$ 50% but clearly fluctuates greatly.

From figs 2,3,4 it is clear that calculated daily radiation totals are closer to observed totals when averaged over longer periods. This is as expected since on the larger time scales there is more opportunity for discrepancies (positive or negative) between calculation and observation to cancel out. Such discrepancies arise from the failure of the calculation to take into account factors other than cloud amount (such as cloud thickness, cloud layering and cloud types).

4. Summary

A formula has been devised, based upon the Savinov-Angstrom equation, to estimate for sites in Austria average daily radiation totals using data on daily total cloud cover.

During the months April-September the formula gives weekly averages of daily solar radiation totals which are within about $\pm$ 12% (rms error) of observed values.

A contributory factor to the poor correlation at the end and at the beginning of the year may be that only one of the observations (at 14.00) is then representative of the daytime cloudiness.

On a monthly or daily basis the equivalent figures are $\pm$ 7% and $\pm$ 50% respectively but the latter figure is subject to considerable variation.

Acknowledgement. This work was partly sponsored by the E.E.C. under contract No. CLI-058-81-UK(H).

Any comments or suggestions on this paper should be referred to the authors.

Meteorological Office, Met O 8a
London Road
BRACKNELL
Berks

March 1983

References:

Dirmhirn, I (1951) Unterschungen uber die Himmelstrahlung in die Ostalpen Archiv. fur Met.Geophys. und Bioklim, SerB,H4.

Dogniaux R and Lemoine M (1982) Classification of Radiation Sites in Terms of Different Indexes of Atmospheric Turbidity. Work performed in 2nd Solar Energy Programme of the C.E.C. Contract No. ESF-003-B-(G).

Kondratev, K (1973) Radiation Characteristics of the Atmosphere and the Earth's Surface.

Thompson, N (1982) Reviews in Agricultural Meteorology No.3 - unpublished document.

FIG 1

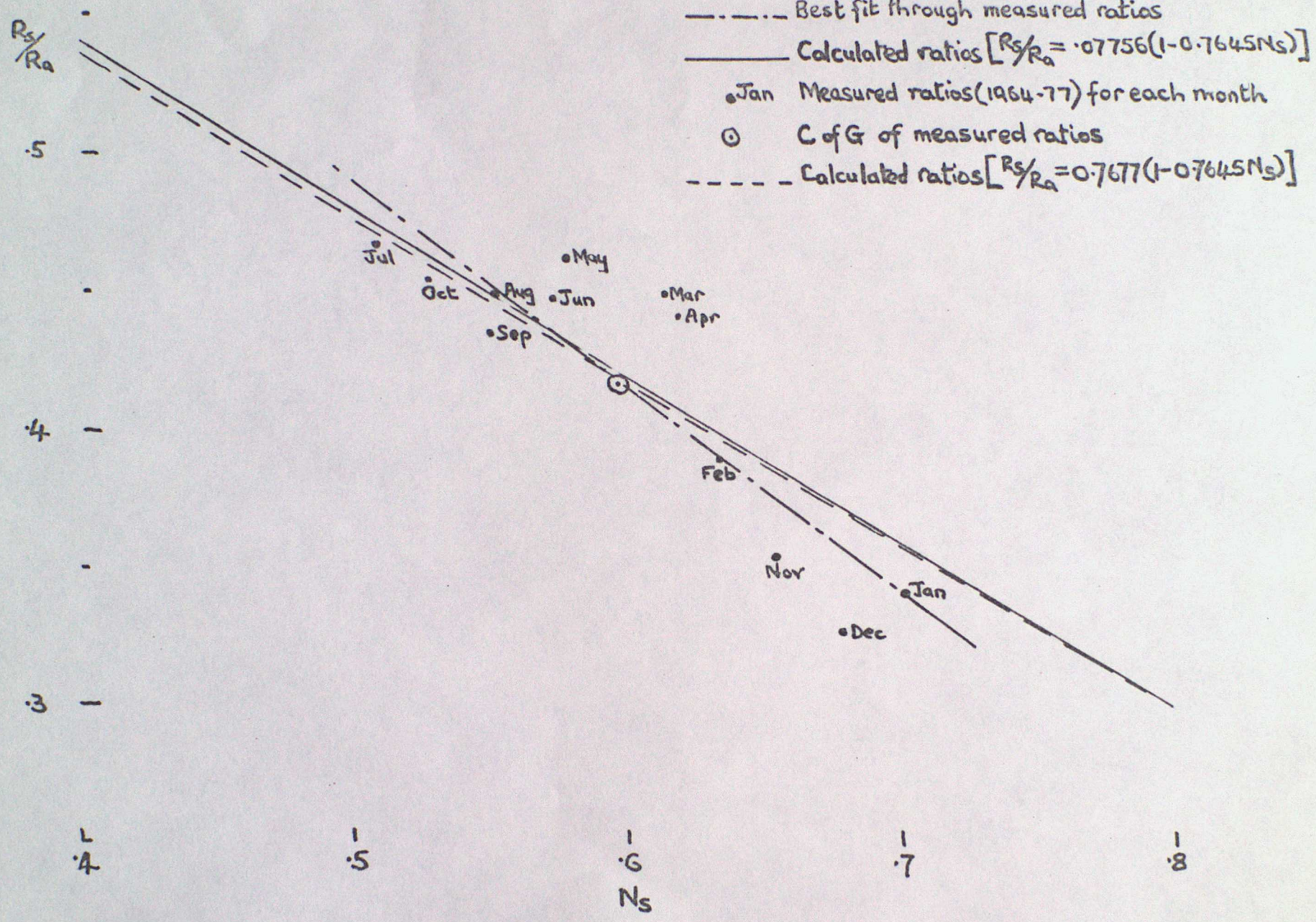
Rs/Ra
·5
·4
·3
Jul
May
Oct
Aug
Jun
Mar
Apr
Sep
Feb
Nov
Jan
Dec
·4
·5
·6
·7
·8
Ns
Best fit through measured ratios
Calculated ratios [Rs/Ra = ·07756(1-0·7645Ns)]
Jan Measured ratios (1964-77) for each month
C of G of measured ratios
Calculated ratios [Rs/Ra = 0·7677(1-0·7645Ns)]

FIG 2

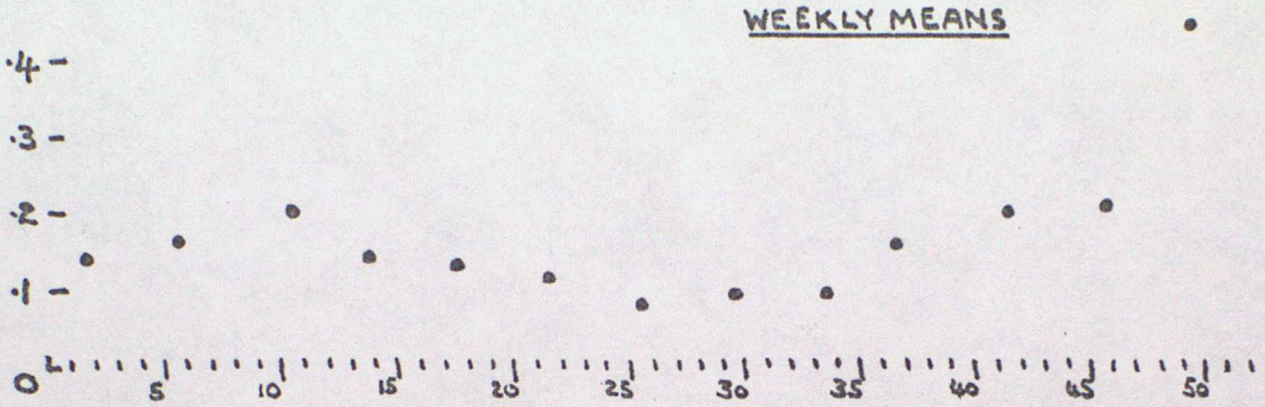

FIG 3

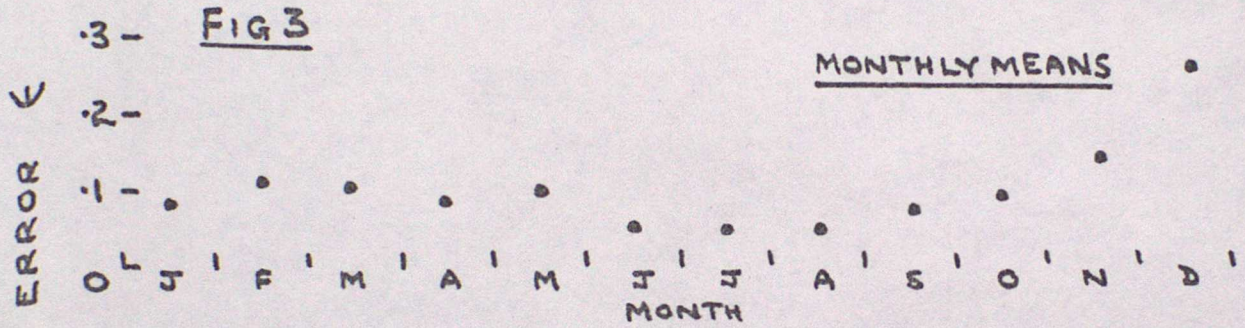

FIG 4